Mesoscopic and Nanoscale Thermodynamics: Fundamentals for Emerging Technologies

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Thermodynamics is a keystone in engineering and science, bridging the gap between fundamentals and applications. However, when one compares what traditional courses on thermodynamics continue teaching and what engineers often do in practice, everyone notices a gap and the gap is widening every year. New emerging technologies deal with bio-membrane and gene engineering, micro-reactor chemistry and microcapsule drug delivery, micro-fluids and porous media, nanoparticles and nanostructures, supercritical extraction and artificial organs. Engineers often have to design processes for systems where classical thermodynamics becomes insufficient, e.g., strongly fluctuating and nanoscale systems, or dissipative systems under conditions far away from equilibrium. Mesoscopic thermodynamics can be defined as a phenomenological approach to the systems and phenomena in which a sub-micron or nanoscopic mesoscale length emerges and where such a length explicitly affects the thermodynamic properties. Finite-size and fluctuation thermodynamics, critical phenomena in fluids and solids as well as in soft-matter materials (such as complex fluids), wetting and interfacial phenomena, self-organized criticality, thermodynamics of pattern formation and fractals are examples of the topics addressed in the mesoscopic thermodynamics. While conventional methods of statistical mechanics remain to be the fundamental background of mesoscopic thermodynamics, a universal approach based on the Landau-Ginzburg local free energy and on the local order parameter(s) can be successfully applied to describing apparently very different phenomena on mesoscales - from the critical fluctuations to the near-surface and interfacial density profile, from micelles and microemulsions to porous media and nanoparticles. This approach utilizes powerful theoretical concepts, such as renormalization-group theory, finite-size scaling, percolation theory, coupling between different order parameters and multicriticality.

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